

# ***Stability & Control Challenges for COMSAC: A NASA Langley Perspective***

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This presentation is designed as a limited-scope “tutorial” and is aimed primarily at the CFDer who has not been exposed to stability and control problems. Examples of some classic S&C problems are used for illustration.



## Outline

- S&C State of the Art
  - Assessment of Capabilities
  - Vehicle Class Issues
- Example Problem Areas
- Recommendations
- Concluding Remarks

S&C is a fundamental technology for enabling flight, but significant problems with the prediction of S&C characteristics persists, especially where separated flow is involved. Even after 100 years of flight, experimental methods still have significant limitations. Experimental and computational tools can and must be complementary.



## S&C State of the Art

- Stability and Control prediction is a *fundamental enabling technology* for any flight vehicle
- S&C experiments are often hampered by scale effects, rig limitations, and lack of flow physics information
  - Leads to unexpected results in flight
  - Impacts cost, schedule, potentially program survival
- The presence of separated flow in all but the most benign flight regimes can lead to unexpected (i.e. unsteady and/or non-linear) behavior and can make rapid, reliable prediction of S&C parameters a difficult task

**CURRENT TOOLS HAVE SIGNIFICANT LIMITATIONS FOR  
CONSISTENTLY PROVIDING HIGH-QUALITY S&C DATA  
IN MANY FLIGHT REGIMES OF INTEREST**

NASA Flight Prediction Workshop (Williamsburg, Virginia, November 2002) brought together experts from government, industry, and academia to discuss problems associated with state-of-the-art flight prediction. Among the concerns highlighted were deficiencies in S&C prediction lack of calibrated CFD tools for aerodynamic prediction in general.



## Flight Prediction Workshop (Nov. '02)

### Breakout Group 1 "Civil and Military Transport Flight Prediction"

<u>Priority</u>	<u>Item</u>
1	High lift / buffet / <b>Stability and control</b>
2	<b>CFD validation / calibration</b>
3	Loads and flutter and facility maintenance/modernization

Some problem areas highlighted at the Flight Prediction Workshop, plus a few added by the author.



## Stoplight Assessment of S&C Issues

### "Improvements Needed"

Jet Interactions (propulsion-induced effects)
High- $\alpha$ Behavior/
Maneuverability--Low Speed
Dynamic Stability--Low Speed
Pitch Trim (e.g. $C_{m_0}$ for L.O.)
Out-of-control modes (spin, falling leaf, tumble, etc.)
Hinge Moments/Control Power
High-lift S&C

### "Critical Shortcomings; High Priority"

Impact of Separated Flow
Transonic Characteristics (high $\alpha/\beta$ , damping, abrupt aero changes)
STOVL Ground Effects--Static and Dynamic
Dynamic Loads
Scale Effects ( $R_n$ and $M$ ) on Stability
Interactions of Complex Controls (e.g. BWB)
Modeling--Unsteady and Non-linear

For illustration purposes, problem areas for four “vehicle classes” are examined.

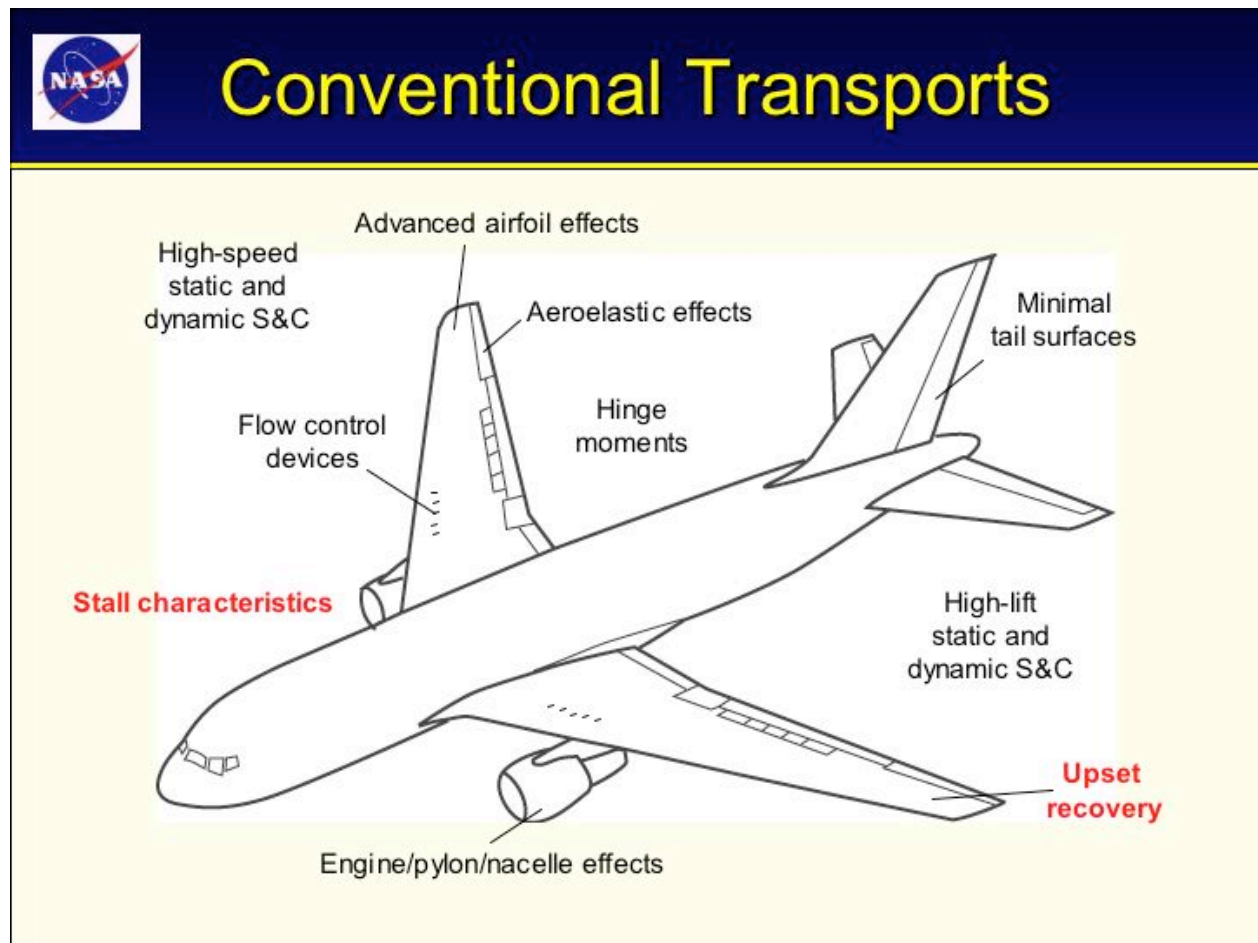


## Vehicle Class Issues

- Vehicle classes examined
  - Conventional Large Transports
  - High-Performance Military
  - Business Jets
  - Unconventional (BWB,UCAV,etc.)



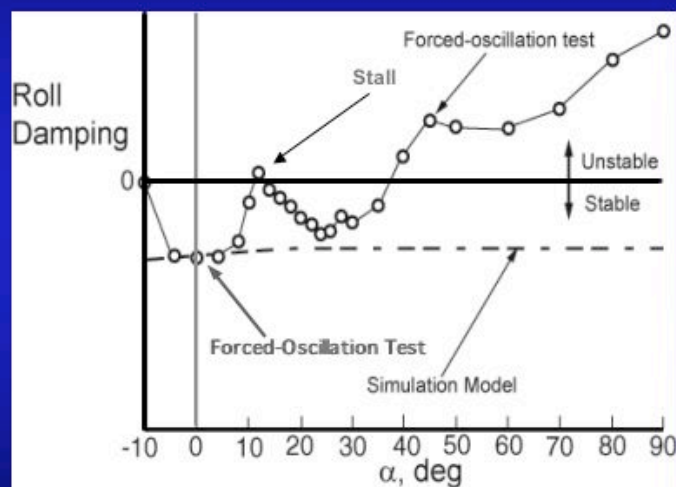
Some issues typically associated with large transports. Items in **red** are highlighted in the example on the following page.



As illustrated by NASA Aviation Safety Program data, roll damping for a large jet transport predicted by the forced-oscillation technique in a wind tunnel is significantly different from that obtained by analytical or handbook methods (e.g. DATCOM), as illustrated by the “Simulation Model” curve. Wind tunnel data indicate that this configuration will have slightly unstable roll damping at stall and will be highly unstable in roll above about 40 degrees angle of attack. Training pilot for stalls and dealing with “out of control” upset conditions may be greatly improved by having better roll damping predictions for simulation.



## Large Transport Roll Damping



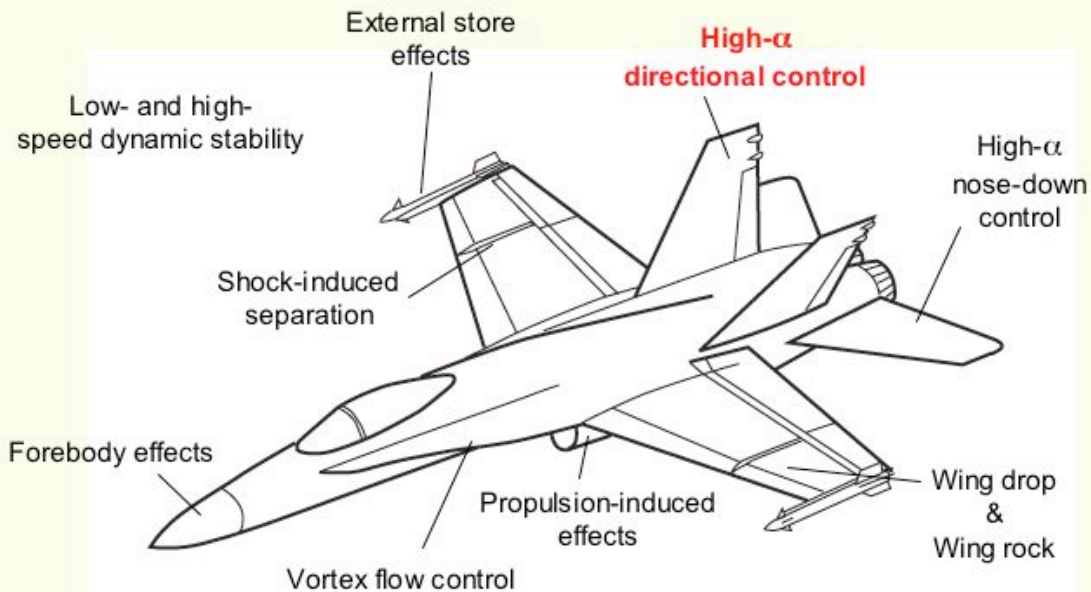
**Prediction of roll damping characteristics critical for outside-of-the-envelope simulator training**



High performance airplanes can have many of the same issues as transports, but there are differences due to the configuration (e.g., sharp leading edge wings, highly swept leading-edge extensions (LEX) or strakes, and close-coupled control surfaces). The fact that these vehicles routinely maneuver at post-stall angles of attack means that flying with separated and vortical flow is the rule, not the exception. Transonic phenomena such as shock-induced wing drop or low-speed wing rock are also not uncommon.



## High-Performance Military



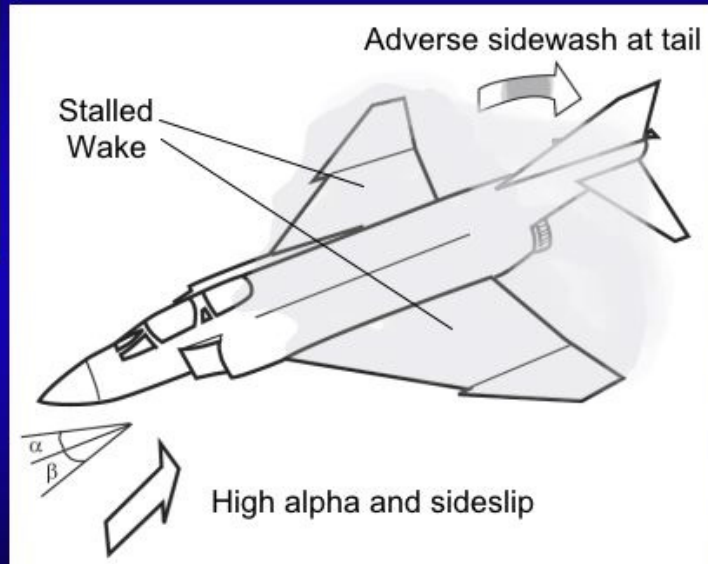
The F-4 was originally designed as a “missile shooter”, not a high- $\alpha$  fighter. During the Vietnam conflict, they were engaged as close-in dogfighters and began suffering significant losses due to spin accidents resulting from loss of directional control at elevated angles of attack. Over 100 Navy and Air Force 100 F-4s were lost before the cause of the problem was identified and resolved by modifications to the leading edge of the wing (slats) to delay stall and improve stall warning. Adverse sidewash at the tail as a contributing factor to loss of directional stability was identified through wind tunnel tests.



## Directional Stability at High- $\alpha$



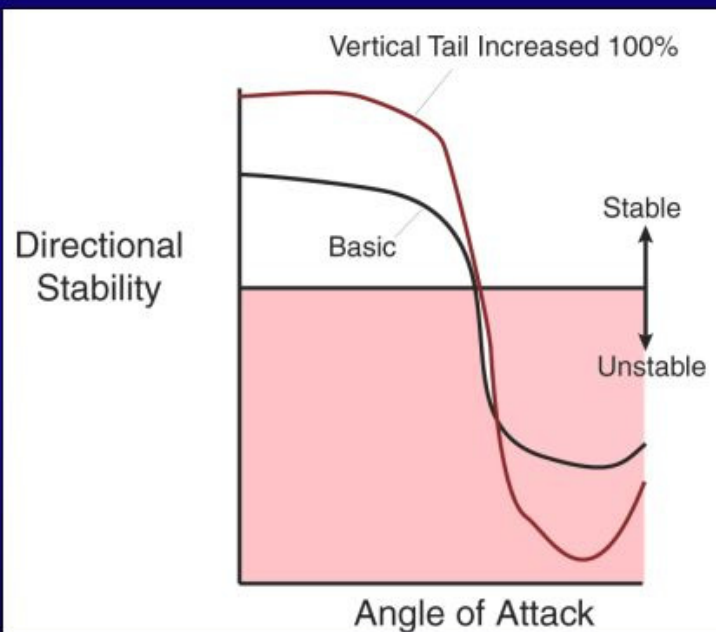
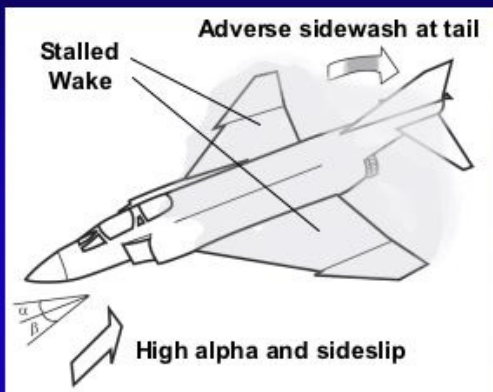
F-4



In this case, adding area to the vertical tail to improve directional stability helps for pre-stall angles of attack (i.e., prior to formation of the large wake from the stalled wing), as anticipated, but actually makes the directional instability worse at high angles of attack due to the adverse sidewash at the tail.



## Directional Stability at High- $\alpha$



Video of F-4 experiencing directional departure during flight-test wind up turn and entering flat spin illustrates how rapidly the airplane goes from controlled to uncontrolled flight.



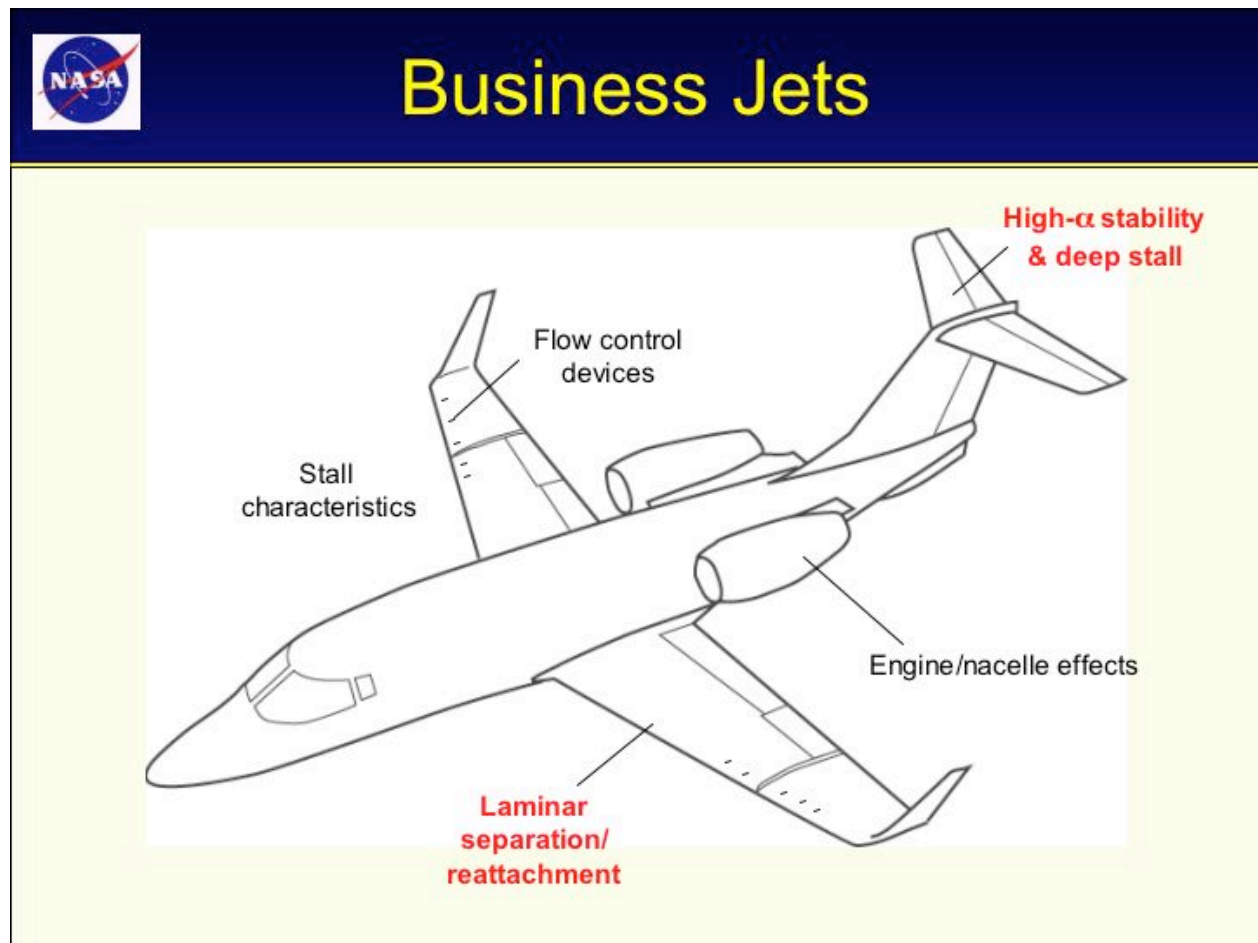
## F-4 Directional Departure

### *F-4 CRASH*

- *Departure*
- *Flat spin*
- *Chute inadvertently released*

Prediction of massively separated, low-energy wakes required for predicting loss of high- $\alpha$  directional stability

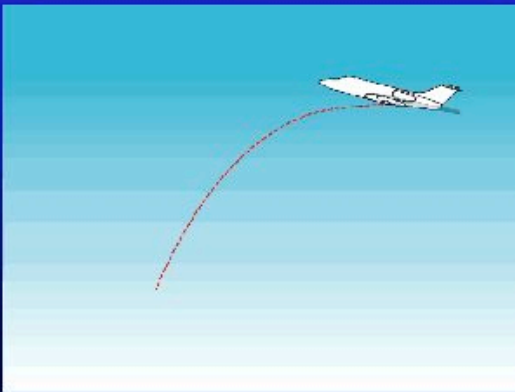
Again, many S&C issues in common with large transports and high-performance fighters, but business jets tend to have T-tails and commonly do not have leading edge devices, potentially leading to issues with deep stall and laminar separation bubbles, respectively.



Wind tunnel data (NOT for configuration in photo at left) show that some T-tail airplanes do not have enough nose-down control authority at high angles of attack to recover from a deep stall.

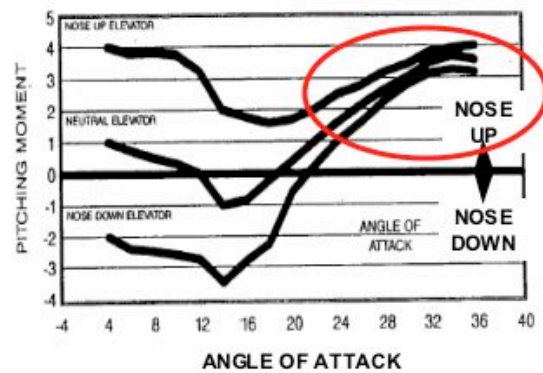


## T-Tail Deep Stall



Example of Business Jet Wind Tunnel

AFT CG, FLAPS 40°



**Requires prediction of  
massively separated wake  
from wing and engine/pylon**



Animation shows laminar separation “bubble” at leading edge at elevated angle of attack (e.g. in landing configuration) progressing to sudden full wing stall on one side after the bubble “lets go” and the entire surface separates abruptly. Large rolling moments are then induced by the asymmetric stall pattern, which is potentially catastrophic if the airplane is at low altitude.

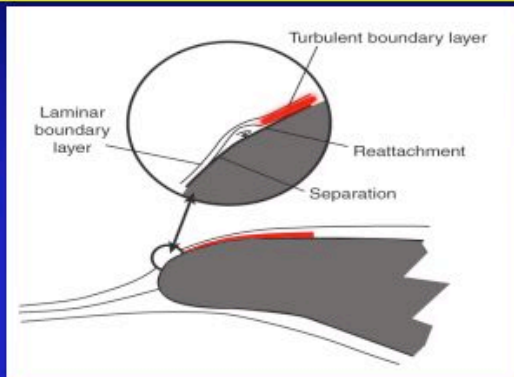


## Impact of Laminar Separation



**Early Lear Model 23**

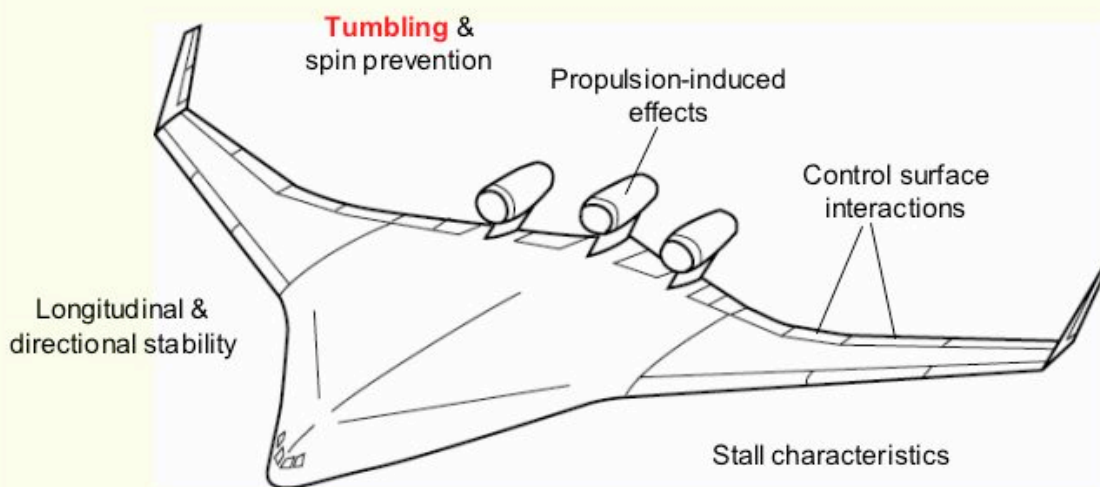
**Initially small flow feature with potentially large impact on S&C**



Unconventional configurations such as flying wings are illustrated by the Blended Wing Body (BWB). Flying wings have many distinct S&C characteristics, depending on the geometry, but may include reduced longitudinal and directional stability due to the lack of a tail, highly non-linear control surface interactions if there are multiple control surfaces, and the potential for entering a tumble mode (i.e., autorotation in pitch).



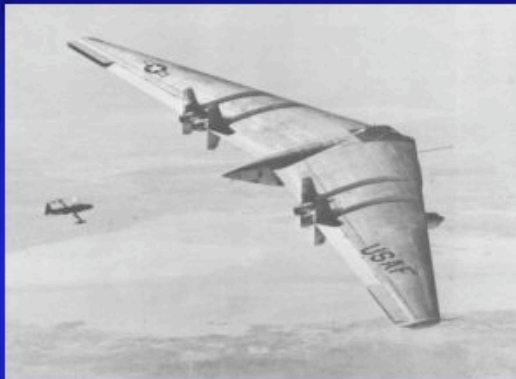
## Unconventional Configurations



The Northrop YB-49 (and earlier XB-35) were advanced all-wing bombers produced in the late 1940s. Longitudinal stability in general (and tumbling in particular) were identified as potential problems for flying wings early on, and experimental studies were conducted to identify potential problem areas. The plot shows wind tunnel pitching moment data for another flying wing which shows that the vehicle is statically unstable in pitch (I.e., the slope of the curve is positive near zero angle of attack), which could lead to a pitch departure if the dynamic pitch damping is such that rotation is sustained over a complete 360 degree cycle.

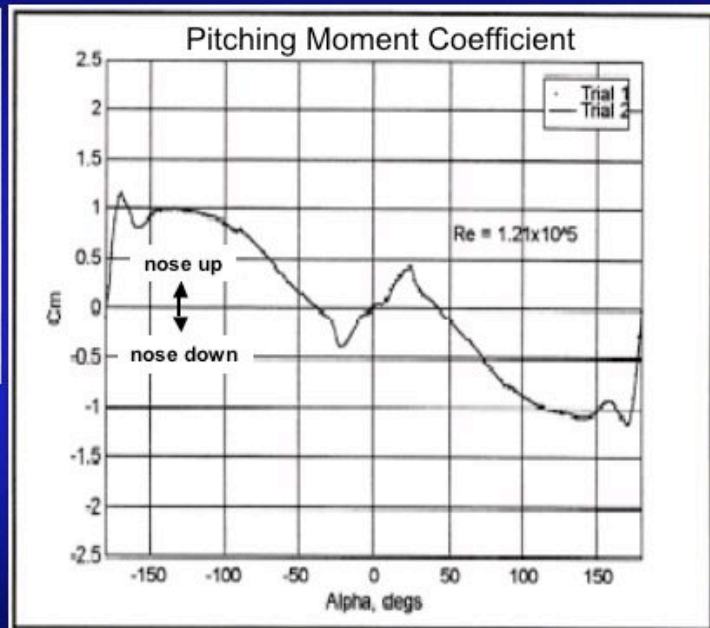


## Autorotation-in-Pitch



YB-49

**Static and dynamic stability characteristics must be calculated over 360 degrees of pitch**



Representative flying-wing pitching moment coefficient



## Autorotation-in-Pitch



Generic flying wing in LaRC Vertical Spin Tunnel



## Recommendations

- Focus on mix of near-term and far-term objectives
  - Combination of component studies and complete configurations
- Collate and assess knowledge of major flow phenomena (stall progression, hysteresis, etc.) to prioritize work
- Critically address the level of code required for specific issues
  - Design, high-fidelity assessments, database, etc.
- Define S&C experimental measurements required for calibration of codes
  - $Rn$ ,  $M$ , flow physics diagnostics, rigs, testbeds, etc.

**S&C community must answer for CFD community:  
“How good is good enough?”**





## Concluding Remarks

- The challenge of predicting aero S&C parameters using CFD is formidable
- The potential payoffs are unprecedented
- Massive amounts of experimental data are available for general guidance
- Very few S&C experiments have been designed for code calibration
- COMSAC must be a close collaboration of the S&C and CFD communities from industry, government, and academia on a national level